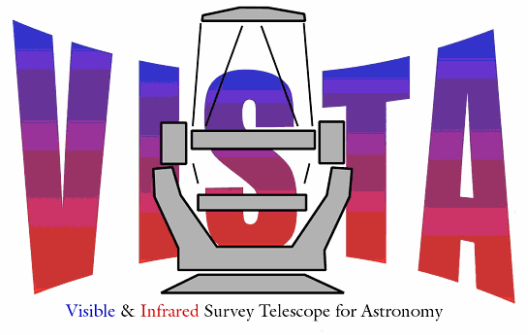

IR CAMERA

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CHANGE RECORD

Issue	Date	Section(s) Affected	Description of Change/Change Request Reference/Remarks
1.0	12/11/03	All	New document
2.0	04/03/04	section 1.4 figure 2 figure 4 section 4.3 figure 7 section 7 section 8 section 9 table 5 table 6 table7 section 11	Added reference to DICB Updated to improve pdf output. Replaced substates CONFIG and PROCESSING with single state BUSY. Corrected typo CCD -> science detector Updated class hierarchy diagram. Module vcmcfg will store config data Third party software references removed Cross referenced DICB Inserted INS subsystem keyword in conversion. Made all keywords fits compliant Added table to indicate keywords defined by other sub systems but used by HOWFS software Commands will be logged in engineering log.
3.0	22/02/05	Various	Major update after Durham/ATC meeting of 17-Feb-05
3.1	17/03/05	Various	Minor corrections
3.2	10/03/06	Various	Multiple changes to match actual code
3.3	5/04/06	Figure 5 Table 1 section 5.2.1	NullFile no longer held in database Null Aberrations
3.4	12/04/06	Figure 2 and Figure 3	Corrected figures provided by Steven Beard

NOTIFICATION LIST

The following people should be notified by email that a new version of this document has been issued and is available on the IR Camera document database:

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1 INTRODUCTION

1.1 Scope

This document describes the design of the HOWFS software. This includes the interface of the HOWFS to the Observation Software (OS) modules of the VISTA IR Camera software (hereafter referred to as the VIRCAM software).

1.2 Acronyms and Abbreviations

BOSS	Base Observation Software Stub
CCS	Central Control Software
DCS	Detector Control Software
EVH	Event Handler Toolkit
FITS	Flexible Image Transport System
HOWFS	High Order Wavefront Sensor
ICS	Instrument Control Software
OS	Observation Software
ROI	Region of Interest
TAT	Tools for Automated Testing
TCS	Telescope Control System
VCHOIA	Vista Camera High Order Image Analysis
VLT	Very Large Telescope

1.3 Applicable Documents

[AD1] Wavefront Sensors Subsystem Design, VIS-DES-UOD-06042-0001, Issue 3.0, 8 Mar. 2004

[AD2] Wavefront Sensors Subsystem Design (Delta PDR), VIS-TRE-UOD-06042-0004, Issue 1.0, 22 May 2003

[AD3] VISTA IR Camera Observation Software Design Description, VIS-DES-ATC-06082-0001, Issue 3.2, 24 Feb. 2005

[AD4] Actuator Patterns, Quasi-Zernikes, and Vibration Mode on the Primary Mirror, VIS-TRE-ATC-02020-0005, Issue 1.0, 15 January 2002

[AD5] Image Analysis Algorithms for VISTA wavefront sensing, VIS-TRE-UOD-06042-0005, Issue 1.0, 12 Nov. 2003

[AD6] Operation of VISTA Active Optics, VIS-TRE-VSC-13030-0001, Issue 1.0, 22 Aug 2003

[AD7] VISTA IR Camera Software User and Maintenance Manual, VIS-MAN-ATC-06080-0020, Issue 1.0, 12 November 2003.

[AD8] High Order Curvature Sensor Sensing Positions, VIS-ICD-UOD-06042-0020, Issue 0.3, 12 October 2005.

1.4 Reference Documents

[RD1] Template Instrument Software User and Maintenance Manual, VLT-MAN-ESO-17240-1973, Issue 4, 31 March 2003.

[RD2] VLT Software Active Optics Design Description, VLT-SPE-ESO-17210-1173, 20 October 1997.

[RD3] Base Observation Software Stub (BOSS) User Manual, VLT-MAN-ESO-17240-2265, Issue 4, 5 April 2004.

[RD4] CCS Event Tool Kit (EVH) User Manual, VLT-MAN-ESO-17210-0771l, Issue 1.8, 6 October 2001

[RD5] VLT Software TCS Auto Guiding and Field Stabilisation Design Description, VLT-SPE-ESO-17230-0933, Issue 3.0, 10 April 2000

[RD6] Installation tool for VLT SW packages, User and maintenance manual. VLT-MAN-ESO-17240-1913, Issue 4, 31 Mar 2003

[RD7] Numerical Recipes in C++: The art of Scientific Computing. William H. Press, et al. 2nd ed. Cambridge Press, 2002.

[RD8] Tools for Automated Testing, User Manual. VLT-MAN-ESO-17200-0908, Issue 1.4, 15 Feb 2001.

[RD9] Central Control Software, User Manual, VLT-MAN-ESO-17210-0619, Issue 2.4, 31 Mar 2004.

[RD10] Data Interface Control Document, GEN-SPE-ESO-19400-0794, Issue 2.0, 21 May 2002.

2 OVERVIEW

The HOWFS has two main tasks, [AD6]. The first one is to provide measurements used in building lookup tables that predict the shape of the primary mirror with any given altitude

and temperature. The second one is to perform a Zero point calibration check once or twice during an observing night.

The HOWFS is based on the curvature sensor principle, [AD1], [AD2], and consequently requires two defocused images of a star. The HOWFS will use the science detector arrays to acquire its defocused images. The defocused images will be produced by selecting a specially designed filter from the camera filter wheel. A layout of the images produced by the HOWFS filter on one of the IR detector is shown in Figure 1. The positions of the HOWFS filters in the filter wheel and the consequent positions of the curvature images on the focal plane are defined in [AD8].

The HOWFS software will only be responsible for doing the image analysis. The HOWFS software will be referred to as the VISTA Camera High Order Image Analysis or vchoia module from now on. The process derived from this module will be known as vchoiaServer. Selection of the appropriate filter and acquisition of the star will be performed by the OS through the ICS, TCS and DCS modules. Figure 2 shows the context of the HOWFS with respect to the other camera and telescope systems. The template sequencer scripts will be responsible for despatching the appropriate commands to the image analysis process. The DCS will store the acquired image in the Data Store as a FITS file. The OS will then append data specific to the exposure, to the header of the FITS file before it is actually processed by the HOWFS software.

During analysis, data will be logged using the CCS logging system, [RD9]. Data produced from the analysis will also be stored in a coefficient file that can be processed offline to produce the lookup table which is used in open loop correction of the primary mirror.

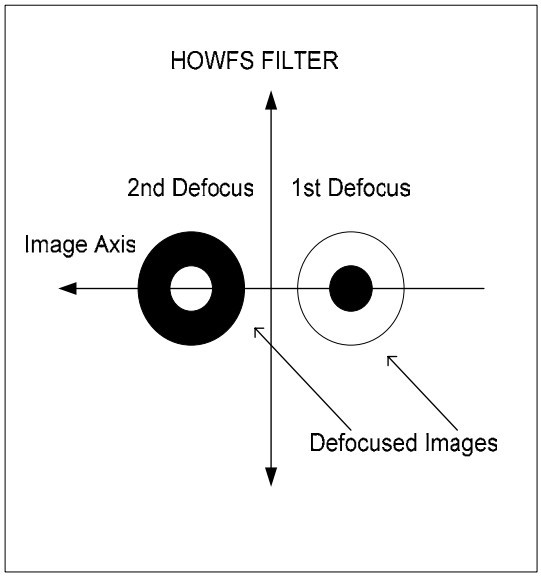

Figure 1: Layout of the images produced by the HOWFS filter on one of the IR detector. (Not to scale)

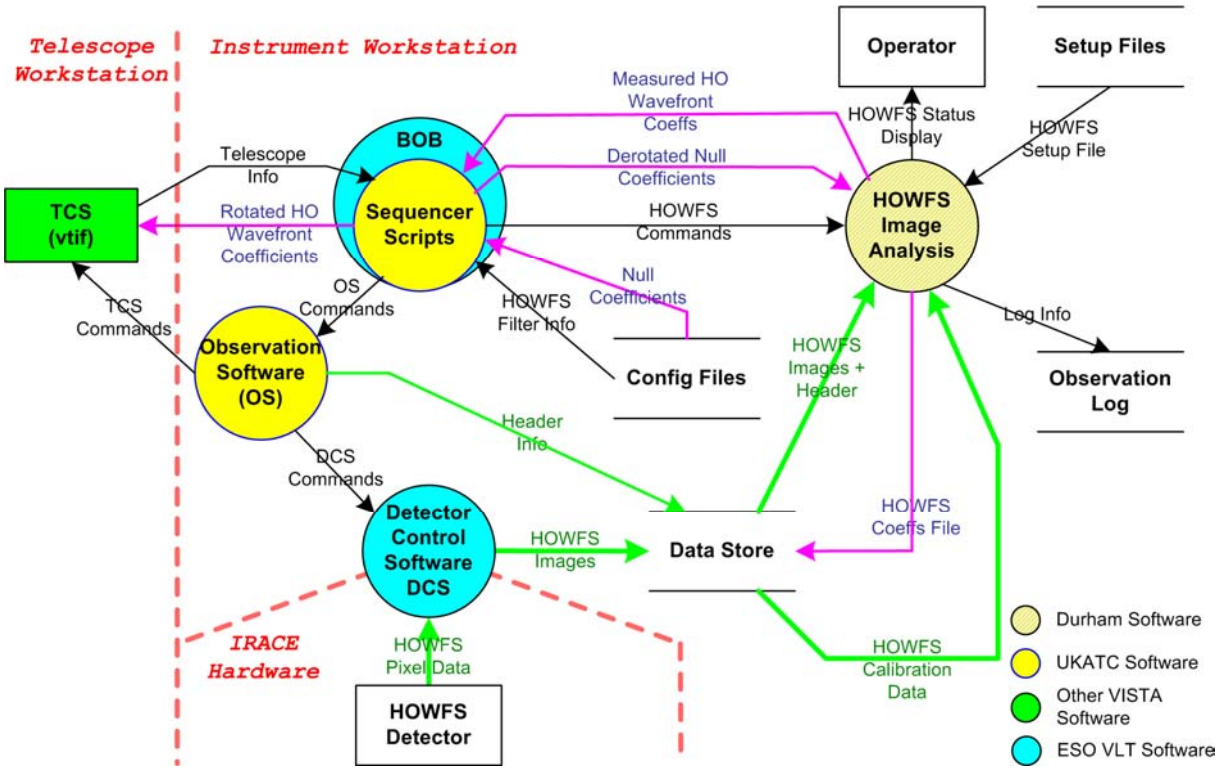

Figure 2: Context diagram showing the interactions between the HOWFS software and the Observation Software

The HOWFS Image Analysis process is known as vchoiaServer and is part of the vchoia module. This process and its interaction with various other modules, is shown in detail in Figure 3. The HOWFS image analysis is driven from sequencer scripts invoked by the ESO Broker for Observation Blocks (BOB). It fits more closely with the ESO model of an on-line data reduction task than with an instrument sub-system. The HOWFS database will be contained within the wvcam environment and the database is created when the wvcam environment is started. The vchoiaServer process connects to that database when it starts up. The sequencer script will communicate with the vchoiaServer process by sending it messages of the form:

msgSend wvcam vchoiaServer "VERSION" ""
msgSend wvcam vchoiaServer "SETUP" "-function HOWFS.STARPOS.X 32.0"
msgSend wvcam vchoiaServer "ANASTAR"

The vchoiaServer process replies with a 256-character-long string. Most replies contain "OK", "FAILED" or the data returned by the command, packed into a string. In the case of the ANASTAR command, the resultant coefficients are not returned. They are instead copied to file and to the database.

This document defines the interface with vchoia and the HOWFS database structure and entries. The interface will be based on the EVH toolkit described in [RD4]. The interface will be implemented by inheriting from the evhSTD_COMMANDS class which provides default implementation for the standard commands.

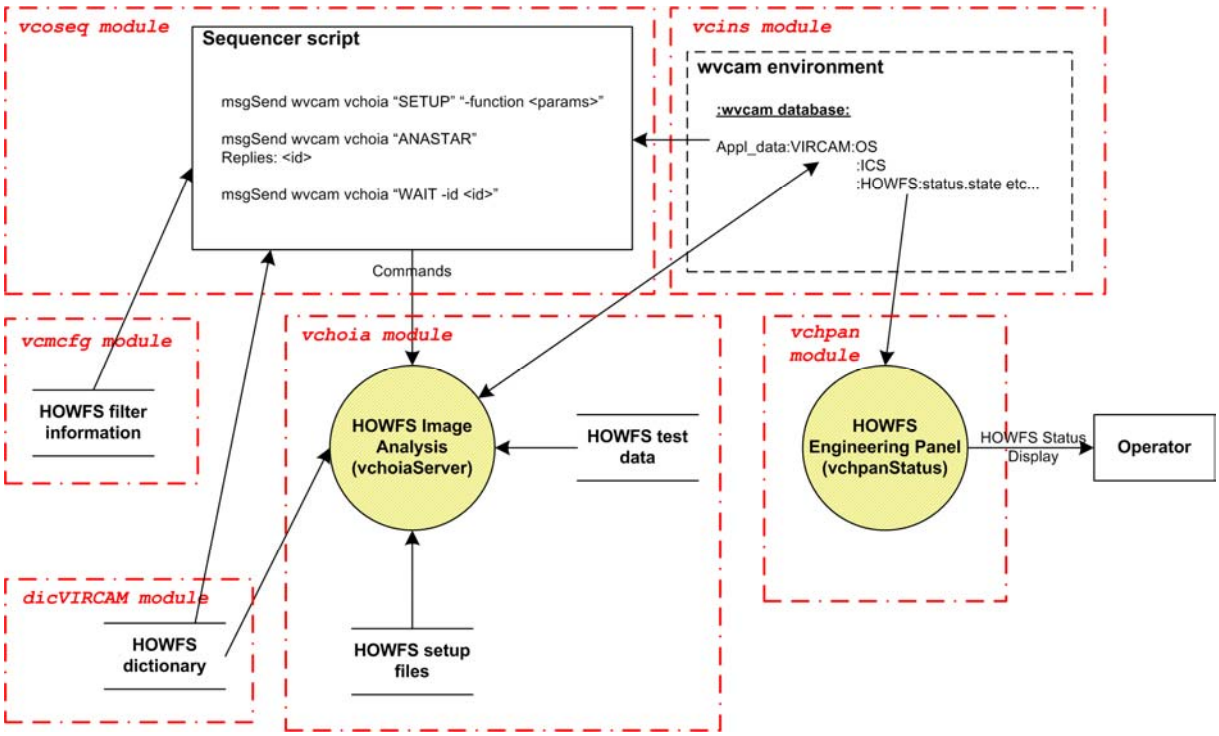

Figure 3 Organisation of the vchoia Module and its Interaction with Other Vista Camera (vc) Modules

3 WINDOWING AND CALIBRATION

Unlike the LOWFS, the HOWFS image analysis software makes use of a FITS file containing the full set of 16 images from the IR image plane. The HOWFS curvature images for this observation are contained in just one of these detector images. The relevant image is identified in the VALIDEXT field in the image header.

The HOWFS software provides its own dark subtraction and flat-fielding capability. The VIRCAM software will ensure that the relevant calibration frames are taken. The names of the relevant files are contained within the database. The HOWFS software expects to find dark and flat-fielded calibrations in these files. The format of these files is identical to that of the curvature image data. It also expects to find a bad pixel mask file. This also has the same format but with a 1 or 0 for each pixel to represent good and bad pixels.

4 OPERATIONAL STATES

The vchoiaServer process can be switched into one of the three standard states OFFLINE, STANDBY and ONLINE. While in the ONLINE state, the process can also be in any one of two sub states, IDLE and BUSY. Depending on the current state, some commands may not be accepted. The various states may be defined as follows:

- OFFLINE - The vchoiaServer process is not running or is in the OFFLINE state. The database should be arranged to show the state of vchoiaServer as "OFFLINE" when the wvcam environment is first started, and the process should have an exit handler that sets the state to "OFFLINE" when it is shut down or dies. The server can be switched to the OFFLINE state by the OFF command.

- STANDBY - The vchoiaServer process is reading its configuration file, or has failed to read its configuration file due to an error. The vchoiaServer process is up and running but unable to process data. The SETUP, ANASTAR, CHECK and WAIT commands are not accepted in this state. (In the event of an error, the ONLINE command can make the process re-read the configuration file and go to the ONLINE state).

- ONLINE - The vchoiaServer process is running and able to process data. The STANDBY command will make the process go into the STANDBY state (for compatibility with the startup tool). Once in the ONLINE state, the process can be in one of two sub-states:

    - IDLE - No processing is taking place. The process can accept an ANASTAR or SETUP command. The process transfers to the BUSY state on receipt of an ANASTAR command. (NOTE: The SETUP command is likely to be very fast, since it only sets parameters, so there is no need to change to the BUSY state during a SETUP).

    - BUSY - Processing is taking place. The process cannot accept a new ANASTAR or SETUP command, and they will return an error. The process returns to the IDLE sub-state when it has finished processing. A STOP or ABORT command can be used to abort the processing and return to the IDLE state immediately.

Figure 4 shows the state chart of process vchoiaServer.

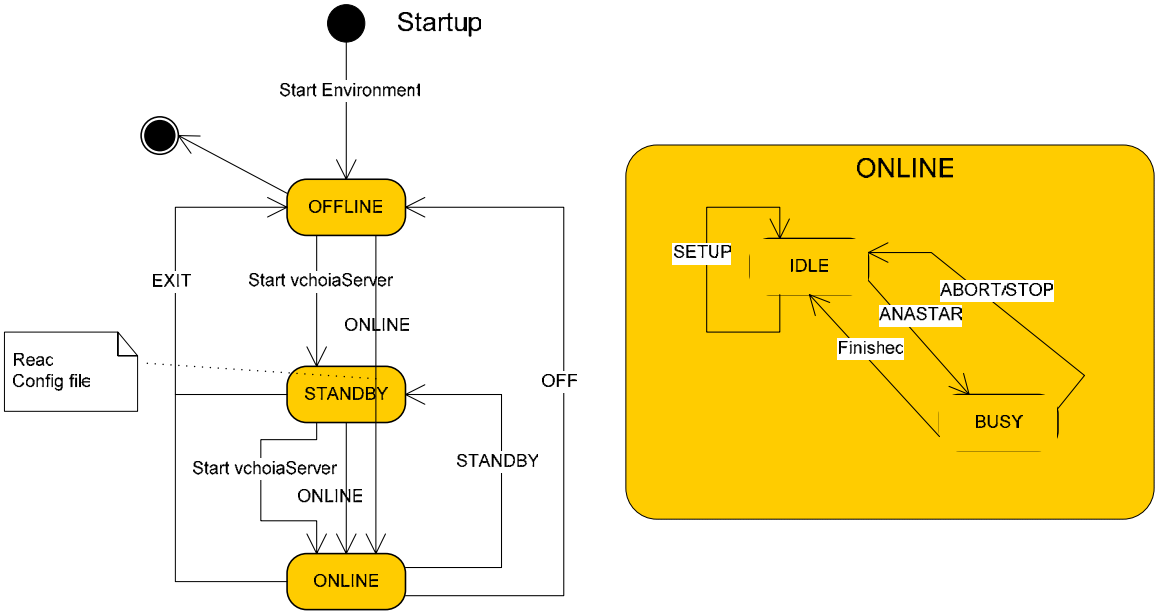

Figure 4: Operational States of process vchoiaServer

5 DATA DESCRIPTION

5.1 Database Definitions

A database that represents the internal state of the vchoiaServer process is setup as shown in Figure 5. The database is loosely based on the VLT software active optics design described in [RD2]. Table 1 provides additional information on the objects listed in the database.

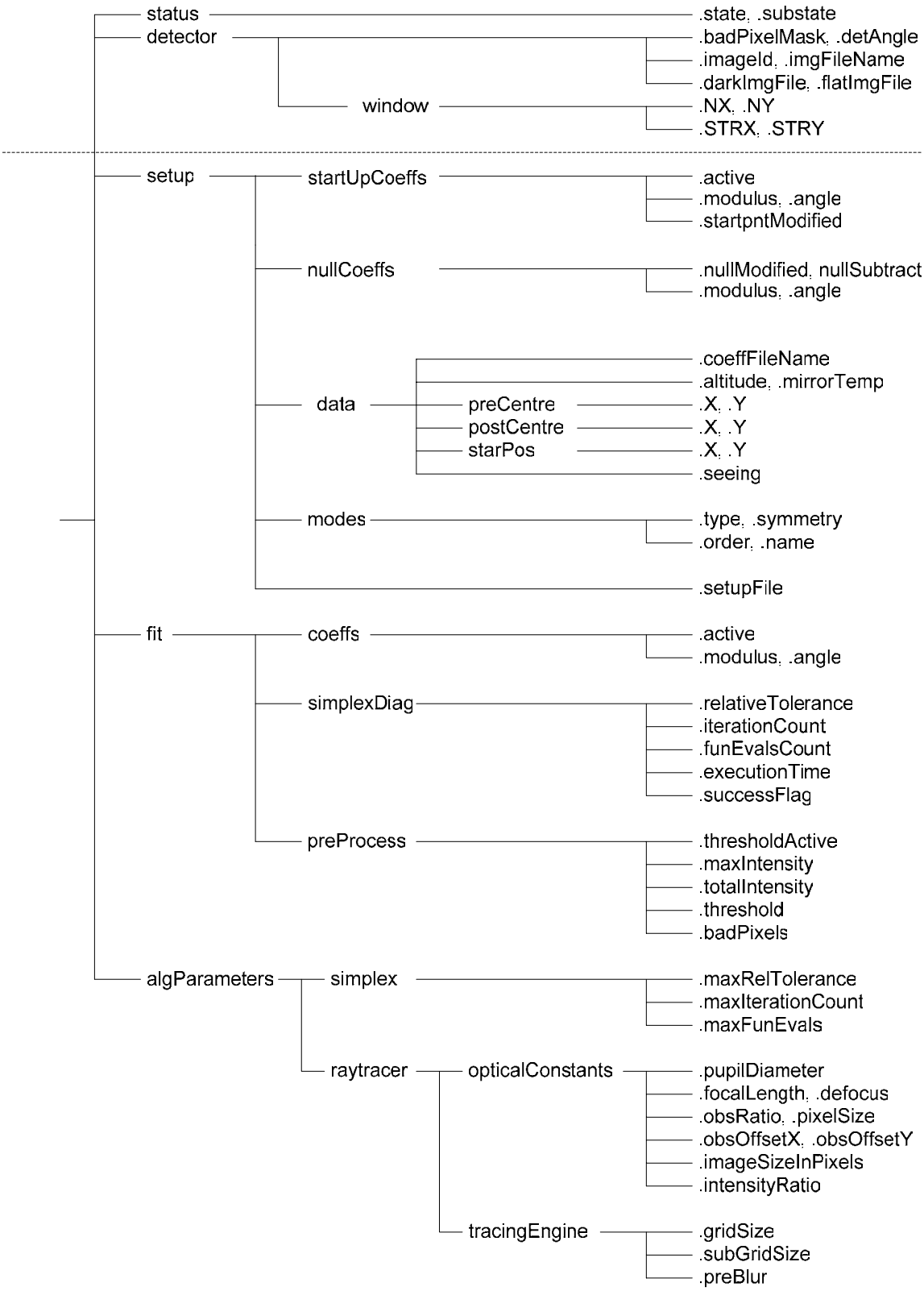

Figure 5 Database structure for module vchoia

Table 1: Definition of variables stored in the database.

Variable Name	Origin	Type	Description
status			
state	Status	String	Standard state information
substate	Statues	String	Detailed state information
detector			
badPixelMask	Config	String	Name of file storing bad pixel mask
detAngle	Config	Double	Instrument angle with telescope axis in degrees
.imageId	Header	Integer	Unique Id of this image
imgFileName	Setup	String	Name of file containing the images to be analysed
darkImgFile	Setup	String	Dark image filename (FITS)
flatImgFile	Setup	String	Flat image filename (FITS)
detector:window			
Nx	Setup	double	Size of ROI in X dimension in pixels.
Ny	Setup	double	Size of ROI in Y dimension in pixels.
STRX	Setup	double	Lower left pixel of ROI in X dimension.
STRY	Setup	double	Lower left pixel of ROI in Y dimension.
setup:startUpCoeffs			
active	Setup	vector of booleans	Indicator to show if mode is to be fitted. If not true, coefficients are used as bias values.
modulus	Setup	vector of doubles	Amplitude of mode in nm.
angle	Setup	vector of doubles	Rotation angle of mode in degrees. (Only applicable to symmetric modes)
startpntModified	Setup	Boolean	Flag to show that the startup coefficients have been manually modified.
setup:nullCoeffs			
nullModified	Setup	Boolean	Flag to show that null coefficients have been modified and are not as in the null file.
nullSubtract	Setup	Boolean	When flag is set, null coefficients are subtracted from analysis result.
modulus	Config	Vector of doubles	Amplitude of mode in nm
angle	Config	Vector of doubles	Rotation angle of mode in degrees (Only applicable to symmetric modes)
setup:data			
coeffFileName	Config	String	Name of file to contain fit coefficients
altitude	Header	Double	Telescope altitude angle in degrees

mirrorTemp	Header	Double	M1 mirror temperature in degrees C
preCentre.X	Setup	double	Centre of pre-focal image in X dimension in pixels.
preCentre.Y	Setup	double	Centre of pre-focal image in Y dimension in pixels.
postCentre.X	Setup	double	Centre of post-focal image in X dimension in pixels.
postCentre.Y	Setup	double	Centre of post-focal image in Y dimension in pixels.
starPos.X	Setup	double	X coordinate of star in focal plane coordinates in mm
starPos.Y	Setup	double	Y coordinate of star in focal plane coordinates in mm
seeing	Header	double	Seeing in arc seconds
setup:modes			
type	Setup	Vector of Strings	Type of mode (Zernike or Elastic)
symmetry	Setup	Vector of integers	Rotational symmetry of the mode
order	Setup	Vector of integers	Order of the mode within its symmetry
name	Setup	Vector of Strings	Name of mode
fit:coeffs			
active	Status	vector	Indicator to show if mode was fitted
modulus	Status	vector	Amplitude of mode in nm.
angle	Status	vector	Rotation angle in degrees. (Only applicable to symmetric modes)
fit:simplexDiag			
relativeTolerance	Status	double	Relative tolerance between best and worst solutions on completion.
iterationCount	Status	integer	Number of iterations used.
funEvalsCount	Status	integer	Number of function evaluations used.
executionTime	Status	double	Time taken for fit in seconds.
successFlag	Status	Boolean	Flag to indicate if simplex analysis was completed within maximum number of iterations and function evaluations.
fit:preProcess			
thresholdActive	Setup	Boolean	If flag set to true, an error occurs if the total intensity is less than the threshold.
maxIntensity	Status	Integer	Highest pixel value in both images.
totalIntensity	Status	Integer	Total intensity of all pixels in both images.
threshold	Setup	Integer	Threshold for total intensity. If sum of

			two images is below this value and thresholdActive is set, an error occurs.
badPixels	Status	Integer	Number of bad pixels in the two images.
algParameters:simplex			
maxRelTolerance	Config	double	Stopping criteria for simplex algorithm. Stop simplex analysis when relative tolerance falls underneath this value.
maxIterationCount	Config	integer	Maximum number of simplex iterations allowed.
maxFunEvals	Config	integer	Maximum number of function evaluations allowed.
algParameters:raytracer:opticalConstants			
pupilDiameter	Config	double	Pupil diameter in metres.
focalLength	Config	double	Focal length in metres,
defocus	Config	double	Defocus of WFS CCDs in mm.
obsRatio	Config	double	Central obscuration ratio with respect to pupil diameter
pixelSize	Config	double	Pixel size in microns
obsOffset.X	Setup	double	Offset of the central obscuration in CCD pixels in the X direction
obsOffset.Y	Setup	double	Offset of the central obscuration in CCD pixels in the Y direction
imgSizeInPixels	Config	integer	Image size in pixels
intensityRatio	Config	double	Intensity ratio of two images.
algParameters:raytracer:tracingEngine			
gridSize	Config	integer	Size of grid of rays in pixels
subGridSize	Config	integer	Sub division of rays in pixels
preBlur	Config	boolean	Flag to indicate if images should be blurred by seeing value. (Normally TRUE).

5.2 Start up coefficients for HOWFS

The HOWFS software normally uses the expected null aberrations at a given point in the focal plane as the starting point for the simplex. To do this, the HOWFS software requires a file listing the values of null aberrations for each position on the focal plane at which a HOWFS measurement will be made. These positions are specified in [AD8]. The null aberrations relevant to the current HOWFS measurement are sent to vchoiaServer. If the values sent are different to those held in the file, the nullModified flag (see below) should also be set. When the analysis starts, and if the startpntModifed flag (see below) is not set, the null aberrations are copied to the starting point aberrations in the data base. These are then the start point for the simplex.

Various flags are provided to allow the analysis to be operated in a non standard way for engineering and commissioning applications. Firstly, the null aberrations may be manually specified. In this case, a flag (nullModified) is set to indicate that the database values differ from the null aberration file. Secondly, the starting point aberrations may be manually specified in the database. A flag (startpntModified) is set to indicate that the start point is different to the null aberrations. The simplex algorithm can be a very slow process. To aid convergence, this latter facility is provided to allow the simplex algorithm to be started close to the expected results. Thirdly, the relevant null aberrations will not be subtracted from the result if the nullSubtract flag is reset.

5.2.1 Null Aberrations File

The null aberrations sent to vchoiaServer are read from a null coefficients file. This file lists the values of null aberrations for each position in the focal plane at which a HOWFS measurement may be made. The format of the file will be that of an ASCII text table. Each row of the table will correspond to a HOWFS position. The columns of the table are listed in Table 2. The initial version of this file will be populated with values resulting from modelling. The table will be updated during commissioning to contain relevant values for the optical systems as built.

Table 2: Columns in the Null Aberrations file (ASCII text table)

Parameter Name	Type	Description
x	double	X coordinate in the focal plane in mm.
y	double	Y coordinate in the focal plane in mm.
modulus0	double	Modulus of aberration mode 0 in nm.
angle0	double	Rotation angle of aberration mode 0 in degrees.
modulus1	double	Modulus of aberration mode 1 in nm.
angle1	double	Rotation angle of aberration mode 1 in degrees.
modulus{n-1}	double	Modulus of aberration mode n-1 in nm.
angle{n-1}	double	Rotation angle of aberration mode n-1 in degrees.

5.3 Detector Setup Parameters

The position of the images on the science detector are defined by specifying the centre of the first defocused image in pixels in X and Y, and similarly for the second defocused image. These positions are specified in the database entries: setup:data:preCentre and setup:data:postCentre. Figure 6 shows the orientation of the HOWFS filter in one position. The blue (lighter shaded) square represents the HOWFS filter, while the green squares represent four of the IR detectors. The image axis is not exactly parallel with the radius of the filter wheel, but is set at an angle such that the axis of the centres of the two defocused images falls along the X axis of the selected detector for HOWFS positions where the Y

offset from the centre of the focal plane is a minimum. This has been exaggerated in the diagram which is not to scale.

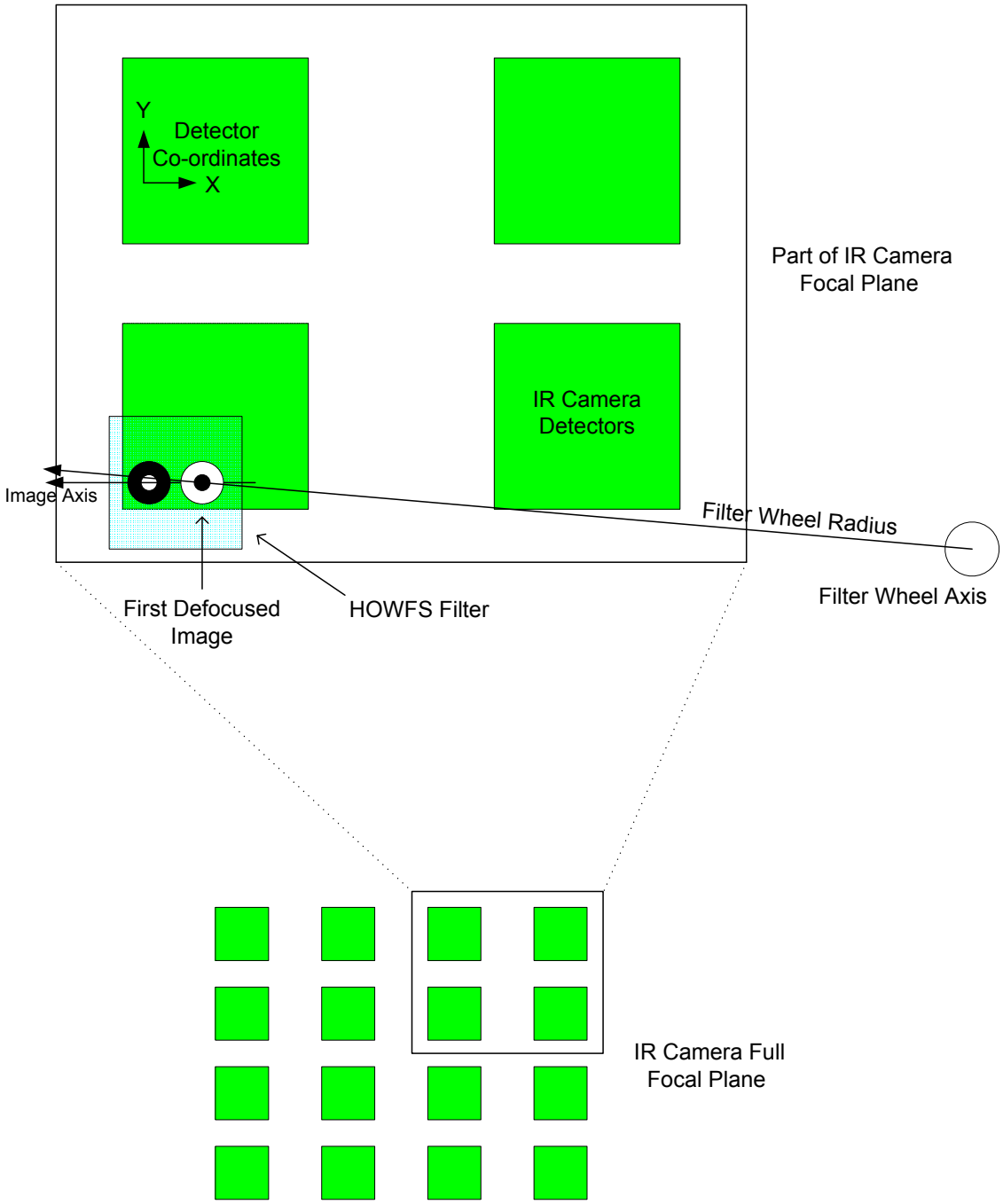

Figure 6: Orientation of the HOWFS Filter and Images.

5.4 Coefficient file

When the analysis is complete, the results are written to the database at fit:coeffs and also to a coefficients file. The coefficients file name is given by database parameter setup:data.coeffFileName. The VIRCAM software will provide a new filename for each observation. The filename will conform to the ESO/VLT naming conventions [RD01] and will be the same as that used for the associated observation with _COEFFS appended to the filename. This file will be used to store data obtained during an analysis. It will be processed offline to generate the look up tables required for correcting the shape of the primary mirror in open loop mode. The format of the file will be that of a 2 column binary FITS table containing the modulus and angle for each mode. Other parameters that are relevant to that HOWFS observation are included as FITS header parameters. These are specified in Table 3. (A full list of FITS header keywords used by the HOWFS software is given in Tables 6 and 7).

Table 3: Headers to the Coefficients FITS File

FITS Keyword	Type	Description
HOWFS.IMGFILE	string	Name of file containing defocused images. Included for reference.
HOWFS.ID	integer	Unique id for each HOWFS observation
TEL M1 TMP	double	Temperature of Mirror in degrees Celsius when image was acquired. (This can be retrieved from Image File but included here for efficiency.)
TEL ALT	double	Telescope Altitude in degrees. (This can be retrieved from Image File but included here for efficiency.)
HOWFS.DATE	string	Date and time when analysis was performed.
HOWFS.RTOL	double	The final relative tolerance value produced by the simplex algorithm.
HOWFS.ITR	integer	Number of iterations performed by the simplex algorithm,
HOWFS.SUCCESS	logical	Indicator to show whether simplex fit was successful
HOWFS.ACTIVE	Vector of Booleans	The active modes vector.
HOWFS.STARPOS.X	double	X position of star in focal plane coordinates in mm
HOWFS.STARPOS.Y	double	Y position of star in focal plane coordinates in mm
HOWFS.DETANGLE	double	Angle of camera with respect to telescope in degrees

6 COMMAND INTERFACE BETWEEN VCHOIA AND OBSERVATION SOFTWARE

The commands listed in Table 4 are those which will be sent from the sequencer scripts to the vchoiaServer process.

Table 4: Commands accepted by the vchoia process.

Command	Optional Parameters	Description
ANASTAR	Start image analysis and return straight away with a string containing a unique ID, starting at 1, or FAILED on error. Returns ID <string>	
WAIT –id <id>	If <id> does not match current ID, or on error, returns ERROR. If BUSY, waits for analysis to complete and then returns OK. If IDLE, returns OK straight away. Note: OK does not guarantee that the Simplex converged. Check the fit:simplexDiag.successFlag attribute to confirm.	
CHECK	Returns non-zero ID if busy, else 0.	
SETUP	Set the specified parameters to the specified values. The keywords available for configuration are listed in Table 6.	
	-function <keyword> <value> [<keyword> <value>]	Define a list of keywords and values to be assigned.
	-file <filename>	Define a file containing a list of keywords and values to be interpreted.
Standard Commands		
STATE	Return the state and substate as state.substate Returns state as <string>	
STATUS	Returns the status as "STATE:" state.substate Returns status as <string>	
STOP / ABORT	Stops Image Analysis Returns OK	
PING	Ask the process to send back an OK reply Returns OK	
STANDBY	Switch to stand-by state Returns OK	
ONLINE	Re-read the configuration file and switch to on-line state. Returns OK	
OFF	Switch to OFFLINE state Returns OK	
VERSION	Return the vchoia module version. Returns version as <string>	
KILL	Terminate the process	
EXIT	Shutdown the process cleanly.	

	Returns OK

7 INTERNAL CLASS DIAGRAMS FOR VCHOIA.

The interface of module vchoia will be developed using the EVH toolkit, [RD4]. Figure 7 shows the hierarchical class structure of the module. This design hierarchy is loosely based on that of the TCS auto guider workstation module described in [RD5]. Class "vchoiaCMDS" will handle all the VLT standard commands. The default implementations provided by the "evhSTD_COMMANDS" will be overridden as necessary. Class "vchoiaSETUP" will handle the SETUP command since a default implementation is not provided. "vchoiaServer" will co-ordinate the activity of the objects used within the process. Class "polySearch" inherits from class amoeba. The latter implements the "SIMPLEX" algorithm as described in [RD7]. Class "rayTracer" is used for raytracing the defocused images. Raytracing as used here is described in [AD5]. Class "polyTables" will store the first order partial derivatives of the polynomials of the modes that will be fitted during the image analysis. The modes are listed in section 11. After the WAIT command has completed, the new coefficients may be read from the HOWFS database or from the specified coefficients file.

Once the VIRCAM software has made an observation using the HOWFS filter and saved the resulting image, Figure 8 shows the exchange of commands between vchoiaServer, the VIRCAM software and the classes implementing the actual image analysis. A higher level diagram showing interaction with the Sequencer can be seen in [AD03 - Fig.14]. The VIRCAM software will send SETUP commands to adjust processing control parameters. Image analysis is then triggered by sending command ANASTAR. vchoiaServer reads the image file, obtains the image size from the database and the seeing value from the image file header. The star X,Y position in the focal plane and the positions of the pair of images on the detector are taken from the database. vchoiaServer then starts the analysis process and returns a unique ID straight away to the Sequencer, or an error (FAILED) on error. While analysis is taking place, the Observation Software can query vchoiaServer to see if analysis has been completed using the CHECK command. Alternatively the Observation Software can issue the WAIT command, and a reply will be sent back as soon as the analysis completes.

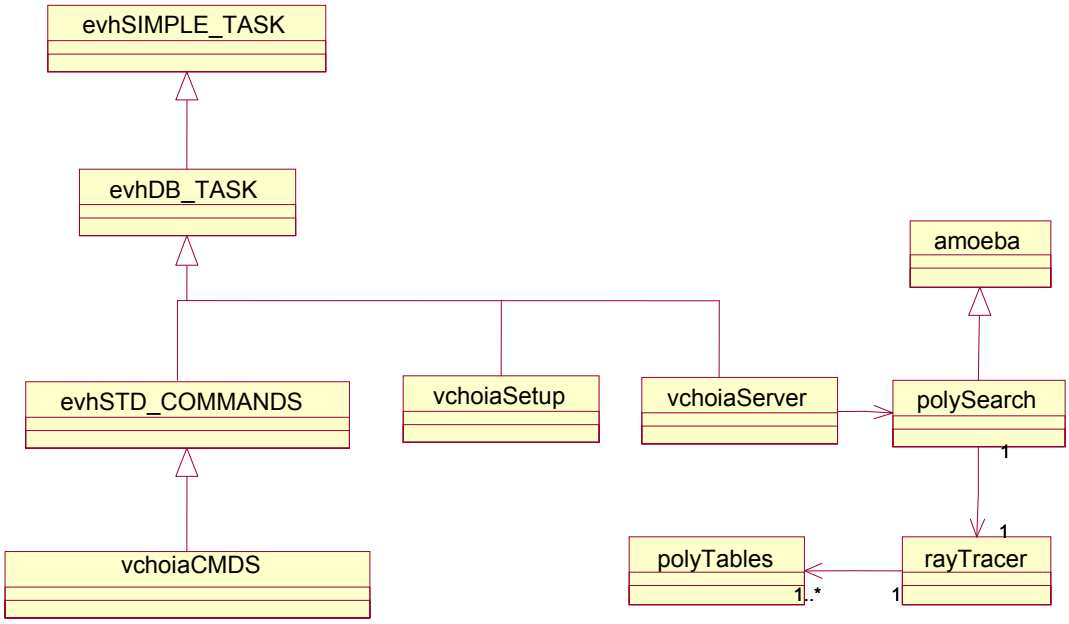

Figure 7 Class hierachy within the vchoia module

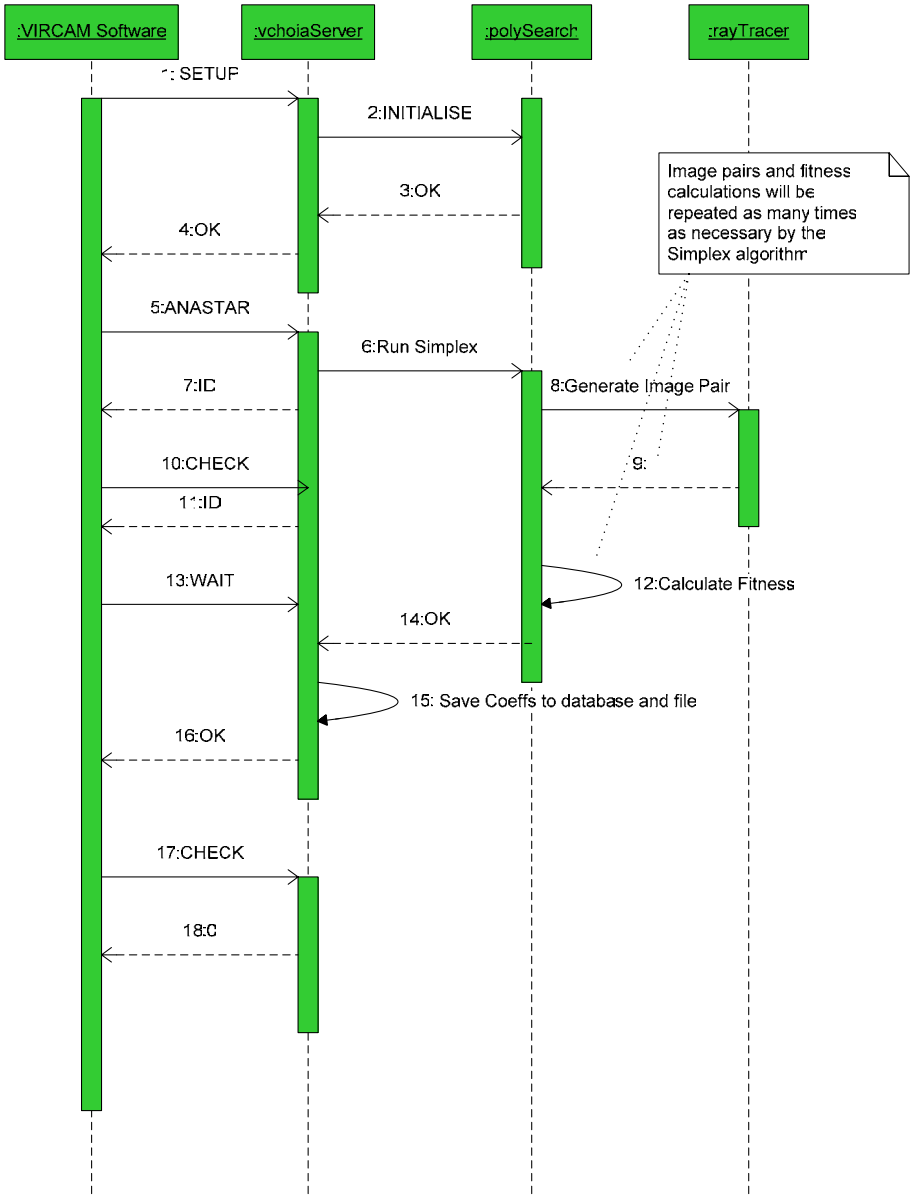

Figure 8 Exchange of messages between the vchoia classes when doing an analysis.

8 DEPLOYMENT

The HOWFS image analysis software, including the vchoiaServer process, will be contained within the vchoia module. The HOWFS database will be contained within the /dbl subdirectory of the vchoia module. This vchoia module will be deployed using the pkgin tool, [RD6]. The vchoiaServer process will run on the instrument workstation and on the same VLT environment (wvcam), [AD7], as the observation software. The pkgin tool will be responsible for creating the necessary VLT environments and for building the database. The HOWFS database will be contained within the /dbl subdirectory of the vchoia module which is assumed to be included in the wvcam database contained in the vcins module as shown in Figure 3. The configuration file and null aberrations file are stored in the vchoia module.

9 TESTING

Testing of the software will be done using ESO's tools for automated testing, TAT, [RD8]. TAT provides a set of tools that can be used as part of a script to test software components. TAT will also configure temporary VLT environments in which to perform the tests. With TAT it is possible to create a battery of tests, which can be run each time the software is updated, to make sure that any existing functionality is not lost. TAT can make bugs identifiable by providing repeatable tests that show the occurrence of a specific error.

The module will be tested as follows:

1) Typical images as observed by the HOWFS during operation will be provided for testing. (A mixture of simulated and experimental images from the lab will be used).
2) Unsuitable images will be provided to see if they can be reliably rejected before starting a time consuming analysis process.
3) Test cases for all the implemented commands will be provided.
4) Pairs of simulated defocused images with known aberrations will be used to test the algorithm.

Test data will be saved within the vchoia module in the /test subdirectory. To save bandwidth during network module transfers, this data may need to be compressed. It can be uncompressed during a 'make' within the /test directory.

10 APPENDIX A: DATA DICTIONARY SPECIFICATIONS

The ESO VLT software standard makes use of keyword dictionaries to define the meaning, data type and format of keywords used within the software. The relevant HOWFS dictionary will be contained within the dicVIRCAM module. The keywords listed in Table 6 are used during configuration of the software module (CFG) and setup prior to an analysis (SETUP). The keywords are designed to meet the requirements of [RD10].

Some of the SETUP keywords will be embedded in the FITS header of the image file and these have been marked as HDR. By logging some of these parameters in the image file

header, the analysis can be run at any time. The HDR keywords represent metadata about the image which is produced when the image is acquired and will therefore remain unchanged throughout the existence of the image. The keywords used in the ESO FITS file, have to comply with ESO's extended hierarchical FITS keywords. A straight forward conversion can be performed on the keywords marked as HDR to derive the ESO compliant FITS keywords. Two examples are given in Table 5.

Table 5: Converting from setup keywords to ESO's Hierarchical FITS keywords

SETUP KEYWORD	ESO EXTENDED HIERARCHICAL FITS KEYWORD
HOWFS.OBSOFFX	HIERARCH ESO INS HOWFS OBSOFFX
HOWFS. STRTPNT.MODMODE3	HIERARCH ESO INS HOWFS STRTPNT MODMODE3

The SETUP command of vchoia will parse all three types of keywords. During configuration, the keywords will normally be passed through a file, rather than on an individual basis. The keywords in the header of the image file will override any previous value sent through the SETUP commands. The vchoia module will also make use of keywords defined by other subsystems. These are listed in Table 7.

Table 6: Keywords used by the HOWFS software.

KEYWORD	PURPOSE	Type	Unit	Comment
HOWFS.PUPDIA	CFG	double	m	Pupil Diameter
HOWFS.DEFOCUS	CFG	double	mm	Image Defocus
HOWFS.OBSRATIO	CFG	double		Central obscuration ratio with respect to pupil diameter
HOWFS.IMGSIZE	CFG	integer	pixels	
HOWFS.PIXSIZE	CFG	double	Um	Pixel size in microns
HOWFS INTRATIO	CFG	double		Intensity Ratio between defocused images due to beam splitter
HOWFS.GRIDSIZE	CFG	integer	Pixels	Grid size of rays used by raytracer in pixels
HOWFS.SUBGDSZ	CFG	integer	Pixels	Subdivision of rays
HOWFS.NAMEMODi	CFG	string		Name of mode to fit
HOWFS.TYPEMODi	CFG	integer		Type of mode. (Zernike or Elastic)
HOWFS.SYMMODi	CFG	logical	T/F	Is this a symmetic mode? i.e. cos and sin terms
HOWFS.ORDMODi	CFG	integer		Order of mode
HOWFS.NULLFILE	CFG	string		File containing null values for the aberrations against radius.
HOWFS.NULLMOD	CFG	logical	T/F	Database null aberrations have been modified
HOWFS.NULLSUB	CFG	logical	T/F	Subtract null aberrations from results.
HOWFS.NULLABER.MODMODEi	CFG, SETUP	double	nm	Modulus of null aberration mode i

HOWFS.NULLABER.ANGMODEi	CFG, SETUP	double	degrees	Angle of null aberration mode i
HOWFS.MAXRTOL	CFG, SETUP	double		Maximum Relative Tolerance
HOWFS.RTOL	HDR	double		Final relative tolerance achieved by the simplex
HOWFS.MAXITR	CFG, SETUP	integer		Maximum Iteration Count of simplex algorithm
HOWFS.ITR	HDR	integer		Final iteration count from the simplex
HOWFS.PREBLUR	CFG, SETUP	logical	T/F	Flag to indicate whether observed images must be blurred
HOWFS.USEMODi	SETUP	logical	T/F	Indicator to fit mode
HOWFS.IMGFILE	SETUP	string		File containing defocused images
HOWFS.DARKFILE	SETUP	string		File containing a dark image
HOWFS.FLATFILE	SETUP	string		File containing a flat image
HOWFS.COFILE	SETUP	string		File to store measured coeffs in with additional data
HOWFS.PATH	SETUP	string		Directory path to where the above files are kept.
HOWFS.BADMASK	SETUP	string		File containing mask with bad pixels indicated.
HOWFS.OBSOFF.X	SETUP, HDR	double	mm	Offset of the central obscuration in X direction
HOWFS.OBSOFF.Y	SETUP, HDR	double	mm	Offset of the central obscuration in Y direction
HOWFS.STARPOS.X	SETUP, HDR	double	mm	X position of star in Focal Plane co-ordinates
HOWFS.STARPOS.Y	SETUP, HDR	double	mm	Y position of star in Focal Plane co-ordinates
HOWFS.PREIMG.X	SETUP, HDR	double	pixels	Detector X co-ordinate of first defocused Image
HOWFS.PREIMG.Y	SETUP, HDR	double	pixels	Detector Y co-ordinate of first defocused Image
HOWFS.POSTIMG.X	SETUP, HDR	double	pixels	Detector X co-ordinate of second defocused Image
HOWFS.POSTIMG.Y	SETUP, HDR	double	degrees	Detector Y co-ordinate of second defocused Image
HOWFS.STRTPNT.MODMODEi	SETUP	double	nm	Starting value of the modulus for the simplex algorithm
HOWFS.STRTPNT.ANGMODEi	SETUP	double	degrees	Starting value of the angle for the simplex algorithm
HOWFS.STRTPNT.MOD	SETUP, CFG	logical	T/F	If T, start-point coefficients have been modified
HOWFS.BADPIX	HDR	integer		Number of bad pixels in analysed images
HOWFS.SUCCESS	HDR	logical	T/F	Flag to indicate if simplex converged
HOWFS.NMODES	HDR	integer		Number of modes fitted by the simplex

HOWFS.PREBLUR	SETUP, CFG	logical	T/F	Flag to indicate if blurring is to be applied
HOWFS.DATE	HDR	string		Date/time when coefficients were produced

Table 7: Keywords needed by HOWFS software but defined by other subsystems

KEYWORD	PURPOSE	Type	Units	Comments
TEL FOCU LEN	CFG	double	m	Focal length of telescope
TEL AMBI FWHM START	HDR	double	arcSec	Seeing at start of acquiring images
TEL AMBI FWHM END	HDR	double	arcSec	Seeing at end of acquiring images
TEL GUID FWHM	HDR	double	arcSec	Seeing derived from auto-guider
TEL ALT	HDR	double	degrees	Altitude of telescope
TEL TH M1 TMP	HDR	double	degrees	Temperature of M1 mirror
DET CHIP ID	SETUP	string		Detector ID of this image
VALIDEXT	SETUP	string		ID of detector image that contains HOWFS images

11 APPENDIX B COEFFICIENTS TO FIT

The following coefficients will be fitted using the simplex algorithm. The actual polynomials are listed in [AD4].

Index	Mode	Constituent Modes	Comments
0	Tilt	Z2,Z3	Ignore these modes
1	Defocus	Z4	
2	Coma	Z7,Z8	
3	e(2,1)	e(2,1)sin, e(2,1)cos	M1 mirror mode
4	e(3,1)	e(3,1)sin, e(3,1)cos	M1 mirror mode
5	e(4,1)	e(4,1)sin, e(4,1)cos	M1 mirror mode
6	e(2,2)	e(2,2)sin, e(2,2)cos	M1 mirror mode
7	Spherical	Z11	
8	e(1,2)	e(1,2)sin, e(1,2)cos	M1 mirror mode
9	e(5,1)	e(5,1)sin, e(5,1)cos	M1 mirror mode
10	5^{th} Order Spherical Defocus	Z22	
11	e(6,1)	e(6,1)sin, e(6,1)cos	M1 mirror mode
12	e(3,2)	e(3,2)sin, e(3,2)cos	M1 mirror mode

12 APPENDIX C LOG FILES

The HOWFS will also log the following events to log files using the CCS logging system, [RD9]. Each event will be time stamped. Two types of log files will be generated depending on the mode of operation:

- Operational log file
  - A record of start-up and shutdown times
  - Each command received from the OS
  - A description of each measurement made and the wave front coefficients derived
- Engineering log file
  - Command received from the OS. (including parameters)
  - Informational messages (when running in VERBOSE mode)
  - Error messages and fault conditions, with diagnostic information

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